CHEM-108

Labs@Home (Gen Chem Labs Continuity During COVID-19)

For the remainder of this semester, we have formulated a series of labs you can safely perform at home using household materials that are commonly available. At the same time, these labs have been designed to give you a meaningful laboratory experience to cover the remaining portions of the course (acid/base, buffers, thermodynamics, electrochemistry).

Background:

In the wild, labs will be very different from those you are used to in gen chem lab on campus, where all the chemicals are usually measured and prepped ahead of time, and all the necessary instrumentation and apparatus are at your disposal. Doing labs at home will require you to clearly understand what you are doing and why, to decide how to best achieve those objectives with the somewhat primitive apparatus available to you. You may also have to improvise and assemble instruments for measurements that you have to make with limited resources at hand. But these circumstances may not be so different from a real chemistry laboratory – in every lab, you will never have everything you need for every experiment, and creativity and resourcefulness are always going to be an asset. But being successful at this also requires that you understand your chemistry inside out, and this is what we hope to achieve with these Labs@Home experiments. Another issue you will run into is the nonuniform quality and concentrations of the materials you are going to be able to source at home. For example, not every store sells the same bottle of vinegar, and even if they do, you won't know its precise concentration. Formulating how to quantify and standardize your materials and solutions will therefore require careful thinking. Furthermore, the variances in experimental data collected under these conditions are expected to be much greater than in the lab, and deriving reliable information for your data will require a thorough statistical analysis.

Logistics:

This entire series of experiments will span 3 weeks, divided into two phases. The class will work in three teams. A TA will manage the work within each team and act as the team’s manager. Each team will have a different assignment during the first phase. Teams will coordinate their work over Slack®.

Phase I (2 weeks)

During Phase I, each team is given a subproject to work on. The goal of each subproject is to build a piece of the infrastructure that is needed for the final experiment in Phase II. At the end of this 2-week period in Phase I, the deliverable we expect from each team is a written protocol that can be shared with all three teams, in order for everyone to be able to reproducibly repeat these protocols at home so he/she can carry out all three parts of the projects individually. These deliverables are important, because without the protocols no one will be able to perform the Phase II experiment. Your TAs will manage the subproject assigned to your team so you can meet the 2-week target for Phase I. Your protocols will also have to be precise, so everyone following the same procedures will derive the same results working individually.

Phase II (1 week)

During Phase II, each of you will use the protocols developed by all three teams from Phase I to perform a final experiment.

The Problem:

The labs that you were not able to perform on campus would have been on buffers, solubility, thermodynamics and electrochemistry. This lab project will cover buffers and solubility.

To perform the Phase II experiment, three components of the lab must be in place:

(A) A protocol telling us how to reliably make a buffer with just household chemicals, without precise devices to measure mass and volume.
(B) A protocol for quantifying the color changes of the acid/base indicator designed by the third team, to correlate colors of the indicator to the pH of a solution.
(C) A protocol for brewing an acid/base indicator at home and designing a uniform protocol for doing titrations.

In a normal chemistry laboratory, these would of course have been trivial. But at home, every one of these can be a challenge. The following are some of the points each team will be addressing. These are fairly open-ended since we have never done these labs before, so be prepared to be creative and adapt your experiments to the circumstances as you learn more about them. You team managers, i.e. your TAs, will guide you throughout Phase I.

Project (A): "Team A" – Quantitative Neutralization

Objective: Figure out how to reliably make buffer solutions with vinegar and baking soda at home without analytical instruments.

To make a buffer at a target pH, we would normally add a strong base (acid) to a weak acid (base) to neutralize a portion of it. At home, we do not have access to strong acids or strong bases, and those we do have access to are limited in selection. In this lab, we will use white vinegar (a solution of acetic acid, CH_3COOH) as the weak acid in order to prepare buffers.

In the lab, we would have employed a strong base to neutralize a weak acid to ensure the neutralization goes to completion, but if we only have a weak base, this neutralization will be incomplete. The base we will be using to neutralize vinegar is baking soda, which is just sodium bicarbonate ($NaHCO_3$), and it is readily available in stores.

$$CH_3COOH\ (aq)\ +\ HCO_3^-\ (aq)\ \rightleftharpoons\ CH3COO^-\ (aq)\ +\ H_2CO_3\ (aq)$$

Even though sodium bicarbonate is only a weak base, the neutralization of acetic acid by the bicarbonate ion can be coerced to completion, because one of the neutralization products, carbonic acid (H_2CO_3), is unstable and decomposes to carbon dioxide, which escapes the solution, and water, which is neutral.

$$H_2CO_3\ (aq) \quad \longrightarrow \quad CO_2\ (g)\ +\ H_2O\ (l)$$

Therefore, using this decomposition reaction, the neutralization reaction between acetic acid and bicarbonate can be shifted entirely to the product side according to Le Chatelier's principle. The first objective of your team is to figure how to reliably prepare a solution with a specific ratio of the base, acetate, to the acid, acetic acid.

The other problem is we don't know the exact concentration of acetic acid in store-bought vinegar. The label usually specifics a weight percentage of acetic acid over the weight of the solution, but this is a very approximate value. Furthermore, the vinegar at all stores do not have the same composition, and everyone in your team will have an acetic acid solution at a different concentration. Fortunately, baking soda sold in stores is 100% sodium bicarbonate, so you can use baking soda to standardize your own acetic acid solution. For those who have a food scale at home, you can use it to weigh out the sodium bicarbonate. For others, you can use the published solubility of sodium bicarbonate to prepare a saturated solution at 0^oC, because ice point is universal and you do not need a thermometer to measure it. You team should do both, and you need to develop the precise protocols for the other two teams to be able to do the same at their own homes. Your TA will guide you.

Project (B): "Team B" – Colorimetry and Its Calibration

Objective: Figure out how to quantify the spectrum of a colored solution, so that the method can be applied to correlate the different colors of an acid/base indicator, provided to you by Team C, to its pHs.

In the lab, pH is easily measured using a pH meter. But at home, we don't have that luxury. Some of you may actually have an aquarium at home and have a digital pH meter you use to measure water acidity. If you do, you can help Team C by providing independent pH measurements to help them more precisely correlate the colors of their indicator to specific pH ranges.

Quantifying the color of a compound is called colorimetry. The problem with reading the color of a solution by sight is everyone has slightly different color perception. The most precise way to determine color of a solution is by taking the spectrum of the light passing through it, as you have done in the spectrophotometry labs this semester. But if you can do that at home, there will be another problem – the light source each of us have at home emits differently, and a white light bulb may not emit light that covers the entire visible spectrum uniformly. Your team will need to come up with a protocol to account for these variations, so everyone is able to measure the same spectrum even when we are all doing it separately employing different light sources.

The obvious question then is how do we find a spectral analyzer at home? Nowadays, all cell phones and computers are equipped with a camera. These cameras are usually solid-state devices that respond to different color light differently depending on its frequency. In conjunction with an appropriate piece of software (e.g. Photoshop) or an app (search for “colorimeters” in the app store), you can analyze the color spectrum of any object fairly easily using a camera. However, beware that the color sensitiviy of every camera is also different, so your team will also have to account for this variation in your protocol.

Finally, to make this reproducible for everyone, each student must be able to calibrate his/her spectual measurements using standard solutions of the same concentrations and identical colors, but we don't have these solutions in one place. However, there are many household products which come in colored solutions, e.g. certain noncarbonated drinks such as Gatorade® comes in many different colors. You can use these store-bought items as a reference to calibration your colorimetry protocol, so everyone can have access to the same standardized solution to calibrate their measurement too. Just be creative.

Project (C): "Team C" – Indicator and Titrations

Objective: Figure out how to make an acid/base indicator solution and use it to carry out acid/base titrations.

The indicator you will be brewing at home is based on the pH sensitivity of red cabbage juice. Red cabbage has a color pigment that has multiple protonation states, and each one has a different absorption spectrum. Your team will develop a protocol for everyone to be able to brew the same indicator at their own homes. There are many resources on the web, and your TA will also guide you.

After you are able to reliably produce your indicator solution, you need to make sure it is producing the color changes at the proper pH ranges. For this, you will have to collect different household chemicals at different pHs to test your indicator. Since you are trying to detect a color change, these solutions must be colorless (or close to colorless).

Some of you may actually have an aquarium at home and have a digital pH meter you use to measure the acidity of the water. If you do, you can help the team by providing another independent pH measurement to more precisely correlate the colors of your indicator to specific pH values. Or members on another team might have one, and you can ask them to help.

You also need to make sure the indicator is able to display the color changes necessary during a titration. Your team should do at least two: (a) an acid titrated by a base of known concentration, and (b) a base titrated by an acid of known concentration. (You may want to consult with Team A on how to quantify the concentrations of store-bought household chemicals). Also, in ordinary titration experiments, one would use a strong base (acid) as the titrant to neutralize an acid (base), to ensure that the neutralization goes to completion. In this experiment, since you won't be able to access a strong base, the titration is intrinsically more complex. You team will have to figure out how this complication impacts the quality of the titration curve you obtain. In general, the co-existence of two weak acid/base systems with the autoionization of water inside the same solution presents a difficult equilibrium problem, and your team might want to attempt this calculation to better understand the intricacies you may encounter related to these weak acid / weak base titrations.

In your protocol, in addition to providing the precise recipe for the indicator, you will need to inform the other teams what some of the technical issues with the titrations may be, how best to carry out these titrations at their own homes, and how they should analyze and understand the results.

LAB INSTRUCTIONS FOR PHASE II WILL BE DISTRIBUTED TOWARD THE END OF PHASE I

Reports:

There is one lab report due at the end of Phase I, which will be a short report. Even though you work as a team in Phase I, an individual report will be required. The Phase II experiment will require a short report.